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STRUCTURE OF THE ANORTHOSITE BODY IN THE ADIRONDACKS

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Introduction.—In No. 3 of the current volume of this *Journal* Dr. N. L. Bowen has discussed "The Problem of the Anorthosites" in a very suggestive and important paper with whose general thesis I find myself in quite hearty accord. It seems to me that the process of formation of anorthosite, as there outlined, is quite the most probable method yet suggested; and I am quite in agreement with the explanation of the general protoclastic and granulated textures which all large bodies of anorthosite exhibit.

When, however, Dr. Bowen comes to consider the universal, or usual, field relations between anorthosite and the accompanying bodies of syenite, and suggests in that connection a structural relationship of these rocks in the Adirondack region, the field facts there, as known to me, seem to be in direct conflict with certain features of that suggestion. The chief point on which we differ does not seem to me in any way to vitiate his main argument, but it does seem desirable to bring it out plainly.

His argument is substantially as follows: that there is (*a*) an intimate connection of syenite with anorthosite wherever the latter is found, as shown by the abundance of rock types intermediate between the two and by the rarity of exposures showing an intrusive relation of the one with the other; (*b*) an intimate association of syenite with Grenville in many places, as contrasted with the anorthosite areas which are comparatively free from Grenville inclusions; also (*c*) the frequent occurrence of Grenville beds overlapping syenite in moderately undisturbed fashion, after the manner of a roof.

Because of the latter relation Bowen argues that it is difficult to picture the syenite and anorthosite as conventional batholiths. He says:

> It is necessary to imagine an early intrusion of a huge plug of anorthosite, followed by an intrusion of syenite which took the form of a hollow cylinder, circumscribing it and invading it only peripherally. All this must take place without throwing the Grenville series into appressed folds, indeed without significant folding of any kind. It is then necessary to imagine that erosion removed every vestige of a roof from the small, interior anorthosite area, and left great stretches of it throughout the broad syenite-granite belt that surrounds it.[1]

Because such relationships seem to him improbable he suggests that the Adirondack eruptive complex consists of a sheetlike mass, or huge laccolith, with syenite overlying anorthosite.

The purpose of this rejoinder is to point out that we are not limited solely to the two alternatives outlined above, and that the data obtained in the field seem to me definitely to contradict the hypothesis that the Adirondack region is composed of a single great sheetlike mass, with syenite overlying anorthosite and bearing all the Grenville exposures of the region rooflike on its back.

Distribution of anorthosite and syenite.—The Adirondack anorthosite is massed in a single great body, rudely heart-shaped, with the apex toward the south. There are a number of small, outlying masses, some of which have some bearing on the questions under discussion. But in addition the continuity of the main mass is interrupted by two considerable *inlying* bodies of other rock, one in the Lake Placid region and one near Keene. Both of these are shown on the state map. At the time when Kemp prepared this portion of the map we were just beginning to recognize the green syenite of the region as a later intrusive and to separate it from the main body of the gneiss in mapping; hence comparatively little syenite is shown as such on this map, and much of what is there mapped as gneiss has been since shown to be syenite also. The two inliers referred to are mapped as gneiss; but Kemp's description of the rocks clearly shows that the Placid inlier consists largely or wholly of syenite and that the same rock is represented in the Keene inlier.[1] Both of these inliers are entirely surrounded by anorthosite, and lie well within the mass.

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[1] *Jour. Geol.*, XXV, No. 3, 223.

By comparison with the anorthosite the syenites occur in separate masses of smaller size, usually much smaller, and there is a large number of such masses. Some of these directly border the anorthosite, but there is nothing like a continuous rim of syenite about it. These syenite masses range throughout the entire region and, in my experience, are no more abundant near the anorthosite than they are away from it. The anorthosite lies in the eastern portion of the Adirondack pre-Cambrian, and its relationships to other rocks on its eastern margin are largely hidden by downfaulting and by the cover of Champlain Paleozoics. But to the west and south abundant syenite ranges away to distances of 60 or 70 miles beyond the anorthosite border; and such pre-Cambrian outliers as those at Little Falls and Middleville bear witness that it runs an unknown distance beyond the pre-Cambrian margin under the Paleozoic cover.

The point here made is that the syenite is spottily distributed over the region, is no more abundant near the anorthosite than it is away from it, and extends so far from the surface exposures of anothorsite that the latter must be given an enormous lateral extent underground, on the supposition that the two constitute a sheetlike mass, with the anorthosite beneath. It is candidly admitted that this point has no particular value if Dr. W. J. Miller's conception of the constitution of the Adirondack pre-Cambrian complex is the correct one. His view is that this complex consists entirely of a foundation of intrusives of the anorthosite-syenite-granite group, upon which fragments of the Grenville cover locally persist.[1] My view is that a complex of Grenville, resting on orthogneiss, existed in the region at the time of the intrusion of the anorthosite-syenite group, that much of this orthogneiss still remains in the region, and that the later intrusives broke through this complex in separate masses, instead of forming one great body.[2] Obviously the presence of a great laccolith constituting the entire region, such as Bowen postulates, is much more possible under the former view than under the latter.

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[1] *Bull. 21, N.Y. State Mus.*, pp. 55–56.

It is quite true that many of the syenite masses are much mingled with Grenville and that the anorthosite area contrasts rather sharply in this respect, as Bowen contends. And I am quite in accord with his view that there has been deeper erosion in the eastern Adirondacks, where the anorthosite occurs, than there has been to the west and south, where the syenite bodies occur, and have repeatedly so stated. Nor am I particularly disposed to quarrel with the view that the anorthosite mass may be laccolithic instead of batholithic in structure. I do not know which it is. The mass has certainly great thickness, since the climb up Mt. Marcy furnishes a 3,500-foot section of pretty clean anorthosite, with no particular indication that the entire thickness may not be vastly greater; then allowance must be made for at least an equal thickness of gabbro and pyroxnite underneath and for an unknown thickness of overlying syenite, since eroded away. Nevertheless, a sheet structure is entirely possible.

Differentiation of the anorthosite body.—If I have correctly understood Dr. Bowen's interpretation of the structure of the region—a sheetlike igneous mass, composed of probable gabbro below, then anorthosite, and finally a cover of syenite and granite, the cover full of fragments from the Grenville roof, and with a certain amount of disturbance occurring during the freezing of the mass, whereby liquid syenite is brought into lateral contact with solid anorthosite—his argument seems to me to imply, or to require, that this sheet was at least equal in size to the present pre-Cambrian area of northern New York and that anorthosite must everywhere underlie syenite. The field evidence, however, seems to me to demonstrate that the full girth of the anorthosite intrusion is represented by the dimensions shown on the present maps and that the outlying syenite bodies represent distinct and slightly later intrusions.

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[1] *Bull. Geol. Soc. Am.*, XXV, 243–64.

[2] *Am. Jour. Sci.*, XXXIX, 288–94.

Dr. Bowen[1] discusses the "Intimate Relation of Syenite and Anorthosite" and makes the following statement:

> This aspect of the anorthosite, i.e., its intimate connection with the syenite, is emphasized in the area as a whole, where, in spite of fairly good exposures, only one other locality showing the intrusive relation of syenite to anorthosite has been found, but where, on the other hand, types intermediate between the two are rather commonly found.

It is chiefly these two points of his paper which I wish to discuss, since my field experience is quite antagonistic to them. I have myself published several localities where dikes of syenite cut the anorthosite, and on the next page of his paper Bowen quotes W. J. Miller as authority for the statement that dikes of syenite cutting anorthosite occur in the Placid region. My thesis is that the general differentiation *in situ* shown by the anorthosite is into anorthosite-gabbro and gabbro, and not into syenite; that such intermediate rocks as do occur are chiefly intermediate between syenite and gabbro, instead of between syenite and anorthosite; and that the demonstrable source of these latter intermediate rocks in many cases, if not in most or all of them, is assimilative attack of a later intrusion upon an earlier, and is not differentiation *in situ*.

The boundary of the anorthosite is in part along faults. Where unfaulted the anorthosite is always found to grade into anorthosite-gabbro, and this into gabbro as the boundary is approached. This change is depicted upon the Long Lake and the Elizabethtown quadrangle maps and occurs also in all other parts of the region in which I have any acquaintance with the boundary. Daly has interpreted this as a chilled border of the anorthosite, and in my judgment this is not only the most reasonable, but in fact the only satisfactory, explanation that can be made of it.[2] If this be true, it follows of necessity that the anorthosite is a differentiate *in situ* from a gabbro intrusion *and that the chilled border determines for us the original size of the mass* at the depth represented by the present erosion surface—in other words, that this particular anorthosite mass cannot be regarded as spreading out underneath the outlying syenite masses and extending throughout the region. If it be argued that the anorthosite body, while cooling, developed a syenite cover, since removed by erosion, I would state that I think this very probable, and would even go so far as to suggest that the Placid and Keene inliers of syenite may be remnants of this cover. If so, it would be in their vicinity that true transitional rocks between syenite and anorthosite would be most likely to occur. Whether they so originated, or represent plugs of syenite rising through the anorthosite, can be determined only in the field with aid of favorable exposures, if any such exist. But even this gives no aid in explanation of the outlying syenite masses.[1]

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[1] *Op. cit.*, p. 211.

[2] *Igneous Rocks and Their Origin*, p. 240.

The syenite-anorthosite boundary across the Long Lake quadrangle suggests intrusive attack of syenite upon anorthosite for its entire length. Along it the syenite develops a basic border of its own, which I have elsewhere endeavored to show is due to assimilation of gabbro and anorthosite gabbro by the molten syenite.[2] In places the syenite thrusts deep salients into the anorthosite, and an excellent sample may be seen on the Long Lake map, coming down to the Raquette River just north of Raquette Falls. It cuts into the anorthosite body to a depth of two miles, cutting out much of the gabbro and anorthosite-gabbro border, though these appear in full width on both sides of the salient. Within it are several inclusions of anorthosite gabbro, five of which are of sufficient size to be delineated on the map. Each inclusion has an aureole of very basic syenite, grading away imperceptibly into the normal rock. These are remnants of the anorthosite-gabbro border which was there before the syenite salient was thrust in, and which has escaped the utter digestion experienced by the remainder.

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[1] It should be noted that the transitional antiperthites described by Bowen are from the Placid region (*op. cit.*, pp. 221–22).

[2] *Bull. Geol. Soc. Am.*, XVIII, 477–92; *Bull. 115, N.Y. State Mus.*, pp. 478–82.

In addition the anorthosite is cut by dikes of syenite in several localities, some of them four or five miles in from the anorthosite border. The field evidence seems clear that the anorthosite had solidified, with a chilled border, and had then been attacked from the side by a mass of molten syenite, which in places cut deeply into it. Along the contact a basic border phase of the syenite was produced, which is not a chilled border *because found only along that part of the syenite boundary which is in contact with the anorthosite,* and hence must be due to the assimilative incorporation of anorthositic material. The product is an intermediate rock, but intermediate between syenite and gabbro rather than between syenite and anorthosite. It differs from the normal syenite chiefly in its large content of ferromagnesian minerals rather than by pronounced difference in the character of the feldspar. It somewhat resembles the gabbro, but ability to distinguish the two is quickly attained in the field.

Dr. Bowen's suggested interpretation of these relations is that disturbance occurred during solidification of the sheet-like mass, after the anorthosite had become practically solid, but while the overlying syenite was still fluid, faulting the one against the other and thus permitting the fluid to laterally attack the solid, giving rise to the intrusive features found in the field. This is a possible cause of such relationships, but it seems to me that the presence of the chilled gabbro border of the anorthosite is fatal to its application in this particular case. That border seems to me to indicate that this is the original size of the anorthosite mass; that it cannot therefore extend westward underneath the bordering syenite; that it cannot possibly underlie the great number of other syenite bodies which range away for distances exceeding 50 miles to the west and south.

The presence of anorthosite outliers in the region somewhat complicates the problem, and might be thought to lend support to Bowen's conception of the structure. The largest of these known to me is that at Rand Hill, Clinton County, which I described years ago. This lies 20 miles distant from the nearest part of the main body, at Keeseville, and seems to me to represent a distinct intrusion, though in all probability an offshoot from the same parent-mass below ground. The other known outliers are all small, are all composed of anorthosite gabbro, lie within a distance of 10 miles from the anorthosite boundary, and are either demonstrable or probable inclusions in the syenite or else are dikelike or pluglike offshoots from the main mass. So far as I know the evidence, they do not at all require belief in the greater extent of the anorthosite mass underground.

Conclusion.—While, therefore, I am quite in accord with Dr. Bowen in the belief that the gabbro, anorthosite, syenite, and (in part) granite bodies of the Adirondacks are all differentiates from a common parent-magma and are closely akin in age, I do not believe that the present surface exposures can be successfully explained as constituting one great igneous body. The anorthosite mass arose to its present position as a gabbro magma, developed a chilled border, differentiated with production of anorthosite and quite possibly overlying syenite, and solidified. The overlying syenite has since been eroded away, except for the possibility that the Placid and Keene inliers may represent portions of it. In so far I can follow Bowen without trouble. But to account for the outlying syenite and granite bodies away from the anorthosite I think that we must resort to the conception of at least one other body of magma, probably of several others, which went through a similar differentiation well below the present surface and from whose upper parts bodies of molten syenite were pushed upward. Some of these came up along the margins of the solidified anorthosite mass while it was still hot and produced the contact relations which we find today.

It is not safe to say, at the present time, that the floor of the entire Adirondack region is constituted of representatives of this one igneous group. It is quite true that the Grenville remnants in the region always rest on igneous rocks which bear an intrusive relation to them. But in my view there are considerable masses of orthogneiss present much older than the rocks of the anorthosite-syenite group; in places the Grenville rests on these, and it is not at all certain that they rest on the younger intrusives; and in many parts of the region these rocks border the anorthosite, as, for example, along Cold River on the Long Lake quadrangle. The conception of a cylinder of syenite enfolding anorthosite is therefore neither a necessary nor a true one; rather, there are a number of separate syenite masses.

ADIRONDACK INTRUSIVES

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In his paper on the "Structure of the Anorthosite Body in the Adirondacks" Professor Cushing offers some objections to the interpretation of Adirondack igneous geology that was given by me in the paper "The Problem of the Anorthosites," and he has kindly asked me to comment upon his objections. It naturally gives me considerable satisfaction that an investigator with Professor Cushing's broad experience of Adirondack geology should accept the more important and vital aspects of my interpretation of the genesis of Adirondack igneous types. I therefore find myself disinclined to object very vigorously to his remarks on features of Adirondack structure concerning which he finds it necessary to disagree with me. This is especially true since it would be presumptuous on my part to differ from him on any point involving actual knowledge of field facts. Nevertheless, there seem to be certain questions of interpretation on which there is room for alternative views.

The common, basic border phase of the anorthosite Professor Cushing considers fatal to the idea of the extension of that rock type laterally as a sheetlike mass beyond the limits of its present exposure. He accepts Daly's interpretation of this border phase as a chilled portion and considers that this phase must be the outer limit of the anorthosite. I, too, accept Daly's interpretation of the basic border, but consider that it is not necessarily an outer limit; it may be an upper limit, or rather a former upper limit. It may therefore represent a chilled upper portion of a laccolithic mass extending far beyond the limits of its present exposure.

It is perhaps necessary to go into this matter in greater detail, and, in order that this may be done, mention will first be made of